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Solid AFFF Technology Investigation

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Solid AFFF Technology Investigation

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16. Abstract (MAXIMUM 200 WORDS) The objective of this fire test program was to quantify the firefighting capabilities of commercially available solid Aqueous Film Forming Foam (AFFF) through a side-by-side comparison with the currently used liquid MIL-SPEC AFFF. By eliminating the water in the concentrate, a substantial space and weight savings is potentially available. The 2.6 m ² (28 ft ²) fire test in MIL-F-24385F was used as a screening method to determine the viability of the concept. It was determined during this program that the commercially available AFFF stick could not extinguish the MIL-SPEC fire and therefore should not be adopted for use on U.S. Coast Guard ships. However, tests conducted with 25-year old solid AFFF pellets demonstrated that the technology is viable. The Coast Guard should encourage the development and testing of solid AFFF technology which achieves performance equal to or similar to that required by the MIL-SPEC.					
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EXECUTIVE SUMMARY

A solid Aqueous Film Forming Foam (AFFF) stick and inline proportioning system were evaluated for potential use on board U.S. Coast Guard (USCG) vessels. The solid AFFF stick technology is intended to replace liquid AFFF stored aboard ship in containers or tanks, and proportioned through the fire main using mechanical equipment. By eliminating the water in the concentrate, a substantial space and weight savings is potentially available.

The 2.6 m² (28 ft²) fire test in the United States (U.S.) military specification for AFFF, MIL-F-24385F, was used as a screening method to determine the viability of the concept. This test has been shown to be an appropriate scaling method to predict large-scale hydrocarbon pool fire extinguishment. Test variables included proportioning method and concentration, AFFF application rate, test fuel, and method of attack. Measures of performance included fire extinguishment and burnback time. Foam quality was also assessed for selected mixtures.

The commercially available AFFF stick could not extinguish the MIL-SPEC fire, even at concentrations and application rates much greater than anticipated. The foam created by the solid AFFF stick did not pass MIL-SPEC foam quality tests, and did not form a film on a hydrocarbon fuel surface.

Older technology solid AFFF was available, and was shown to meet or come close to the requirements of the MIL-SPEC tests used in this study. While this material is not commercially available, these results demonstrated that the technology is viable. The commercially available solid AFFF stick technology assessed in this study should not be adopted for use on USCG ships. The Coast Guard should encourage the development and testing of solid AFFF technology which achieves performance equal to or similar to that required by the MIL-SPEC.



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TABLE OF CONTENTS

EXECUTIVE SUMMARY	V
LIST OF FIGURES	IX
LIST OF TABLES	IX
LIST OF ACRONYMS	XI
LIST OF DEFINITIONS	XII
1 INTRODUCTION	1
2 OBJECTIVES.....	1
3 TECHNICAL DISCUSSION	1
3.1 Solid AFFF Technology Description	1
3.2 Test Selection	3
4 APPROACH	4
5 MEASURES OF PERFORMANCE.....	4
5.1 Concentration	4
5.2 Fire Extinguishment	5
5.3 Burnback and Ignition Resistance.....	5
5.3.1 Burnback	5
5.3.2 Film Formation and Sealability	5
5.3.3 Expansion and Drainage	6
6 TEST FACILITIES, EQUIPMENT, AND INSTRUMENTATION	6
6.1 Test Facility.....	6
6.2 Fire Pans.....	6
6.3 Fuel.....	6
6.4 AFFF	7
6.4.1 Liquid AFFF Concentrates	7
6.4.2 Solid AFFF.....	7
6.5 Creation of AFFF Solutions.....	8
6.5.1 Solid AFFF Stick	9
6.5.2 Solid AFFF Pellets.....	10
6.5.3 MIL-SPEC and Commercial Liquid AFFF.....	10
6.6 Fire Extinguishing System	11
6.7 Instrumentation and Photography	11
6.8 Test Parameters and Procedures	11
6.8.1 MIL-F-24385F-based Fire Test and Burnback Parameters and Procedures.....	12
6.8.2 MIL-F-24385F-based Foam Quality Parameters and Procedures	12
7 RESULTS OF MIL SPEC AFFF BASELINE TESTS	13



TABLE OF CONTENTS (Continued)

8 RESULTS OF COMMERCIALLY AVAILABLE SOLID AFFF STICK..... 13

8.1 Initial Tests of Solid AFFF Stick 13

8.2 Solid AFFF Premix Solution 14

8.3 Solid AFFF Inline Proportioning Test 16

9 RESULTS OF EXPERIMENTAL PROTOTYPE SOLID AFFF STICK..... 16

10 RESULTS OF TESTS WITH 3M SOLID AFFF PELLETS 18

11 RESULTS OF SHIPBUILDER TESTS 18

12 RESULTS OF EXPANSION, DRAINAGE, BURNBACK, AND FILM AND SEAL TESTS 20

13 CONCLUSIONS AND DISCUSSION..... 21

14 RECOMMENDATIONS 24

15 REFERENCES 25

APPENDIX A MATERIAL SAFETY DATA SHEET FOR SOLID AFFF STICK..... A-1

APPENDIX B DATA SHEET AND PROCEDURAL CHECK LIST..... B-1



LIST OF FIGURES

Figure 1. POK components with Quick Stik technology (proportioning system, 60 gpm nozzle, and 20 gpm nozzle).	2
Figure 2. POK inline proportioner.	2
Figure 3. Commercially available solid AFFF stick, with protective wrapper (removed when in use).	7
Figure 4. Experimental prototype #2 blue solid AFFF stick.	8
Figure 5. Creation of foam premix solution using inline solid AFFF proportioners.	9
Figure 6. Direct inline proportioning and nozzle setup.	11
Figure 7. Aerated MIL-SPEC AFFF compared to solid AFFF.	22
Figure 8. Comparison of fire knockdown between MIL-SPEC AFFF and commercially available solid AFFF.	22
Figure 9. Comparison of fire knockdown between MIL-SPEC AFFF and 3M solid pellet AFFF.	23

LIST OF TABLES

Table 1. Approval test summary.	3
Table 2. Results of baseline MIL-SPEC AFFF tests.	13
Table 3. Results of 2.6 m ² (28 ft ²) fire tests of commercially available solid AFFF stick.	15
Table 4. Results of 2.6 m ² (28 ft ²) fire tests of experimental prototype solid AFFF sticks.	17
Table 5. Results of 2.6 m ² (28 ft ²) fire tests of 3M solid AFFF pellets.	19
Table 6. Results of shipbuilder demonstration tests.	19
Table 7. Results of foam quality tests.	20



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LIST OF ACRONYMS

AFFF	Aqueous Film Forming Foam
ASTM	American Society for Testing and Materials
CBD	Chesapeake Bay Detachment
IBC	Intermediate bulk container
IMO	International Maritime Organization
MIL-SPEC	Military Specification
MOGAS	Motor gas (commercially available gasoline)
MSC/Circ.	Maritime Safety Committee/Circular
MSDS	Material Safety Data Sheet
NFPA	National Fire Protection Association
NRL	Naval Research Laboratory
PEG	poly (ethylene glycol)
QPL	Qualified Products List
U.S.	United States
UL	Underwriters Laboratories, Inc.
USCG	United States Coast Guard



LIST OF DEFINITIONS

25% (50%) drainage time	the time for 25% (50%) of the liquid content of a foam to drain out
25% burnback time	the time it takes for the fire to become re-established over 25% of the pan surface area after a small initiating fire is placed in the center of the pan
Application density	volume of foam required to extinguish a fire area, L/m^2 (gal/ft ²)
Application rate	flow rate of foam discharge divided by the fire area, Lpm/m^2 (gpm/ft ²)
AFFF	a foam concentrate or solution consisting of a mixture of hydrocarbon and fluorinated surface active agents which has the ability to form an aqueous film on the surface of some hydrocarbons
Expansion ratio	the ratio of the volume of foam to the volume of foam solution from which it was made
Foam	an aggregate of air-filled bubbles formed from an aqueous solution of suitable foam concentrate
Foam concentrate	a liquid which, when mixed with water in the appropriate concentration, gives a foam solution
Foam solution	an aqueous mixture of foam concentrate and water
Gentle application	the application of foam to the surface of a liquid fuel via a backboard, tank wall, or surface
Premix solution	foam solution prepared at a predetermined concentration and stored in a tank for discharge, without proportioning during the discharge.
Solid AFFF concentrate	the stick containing the AFFF chemicals that is used in either the POK inline proportioner or nozzle to produce the foam solution. During this assessment, the concentrate will be referred to as an AFFF Stick
Solid AFFF proportioner (inline)	a flow-through device that contains the solid AFFF concentrate that is installed at the inlet to a firefighting hose line
Spreading coefficient	a measurement of the ability of one liquid to spontaneously spread across another



1 INTRODUCTION

The U.S. Coast Guard (USCG) currently uses Military Specification (MIL-SPEC) (liquid) Aqueous Film Forming Foam (AFFF) concentrate and proportioning systems to combat Class B fires onboard USCG ships. The AFFF concentrate, stored in tanks aboard ship, is proportioned with sea water from the fire main to create foam solution. The concentrate is proportioned at 3 percent on USCG ships (3 parts concentrate to 97 parts sea water). The concentrate itself is composed mostly of water and solvents, up to 75 percent, along with the surfactants which create the film-forming foam solution that suppresses fuel vapors.

The liquid AFFF concentrate has considerable volume and weight (ranging from 454 kg (1,000 lb) on small patrol craft to over 2948 kg (6,500 lb) on the high endurance and polar class cutters). Weight and space savings could be achieved if some or most of the water could be eliminated from the concentrate. An emerging technology, solid AFFF, is being advertised as having equivalent firefighting capabilities as liquid AFFF concentrate and offering significant storage and weight advantages over existing liquid AFFF concentrate. Based on the manufacturer's claim, the weight and space savings might be almost two orders of magnitude.

2 OBJECTIVES

The objective of this fire test program was to quantify the firefighting capabilities of commercially available solid AFFF through a side-by-side comparison with the currently used MIL-SPEC AFFF. This side-by-side comparison was conducted using the MIL-SPEC test parameters as an initial screening method to determine the viability of the concept.

3 TECHNICAL DISCUSSION

3.1 Solid AFFF Technology Description

POK of North America, Inc. (hereafter referred to as POK) is an innovative manufacturer of firefighting equipment and agents. Located in Cambridge, MD, POK manufactures two types of solid AFFF components (nozzles and proportioners) that incorporate what they refer to as "Quick Stik" technology. These nozzles and inline proportioners use small, easy-to-use solid cartridges of foam or wetting agents to produce firefighting solution. As water passes over and around the solid stick, foam solution is created. The solid cartridge itself is supplied by Buckeye Fire Equipment, Kings Mountain, NC. Buckeye also manufactures MIL-SPEC liquid AFFF concentrate. No eductors or pails of foam concentrate are needed with the solid stick technology. Some of the POK components that incorporate Quick Stik technology are shown in Figure 1. This technology is commercially available for purchase and installation.





Figure 1. POK components with Quick Stik technology (proportioning system, 60 gpm nozzle, and 20 gpm nozzle).

According to the manufacturer, the POK equipment is machined out of high-grade aluminum alloy impregnated with a trademark Teflon® finish for durability. Foam sticks are available for combating both Class A and Class B fires. The Class B foam sticks use an Underwriters Laboratories, Inc. (UL) Listed foaming agent manufactured by Buckeye. Each stick is reported to make 1500 L (~400 gal) of foam solution.

During this investigation, the foam solution was made by either diluting the solid cartridge in a known volume of water or by using a POK inline proportioner (Model 90054) designed for use with a 3.81 cm (1½ in.) fire hose. The proportioner consists of a tube with hose fittings on each end and a perforated sieve in the center of the tube. The proportioner is designed for one directional flow (i.e., the water needs to flow through the tube in one direction). This flow direction is noted by an arrow on the tube. The Buckeye stick is installed in the perforated sieve within the tube. The perforations in the sieve allow the water to dilute the solid stick as well as to agitate the foam solution. The inlet to the perforated sieve has openings to ensure sufficient water flow through the tube. A picture of an inline proportioner is shown in Figure 2. For these tests, a transparent proportioner was used to monitor the status of the stick during discharge.

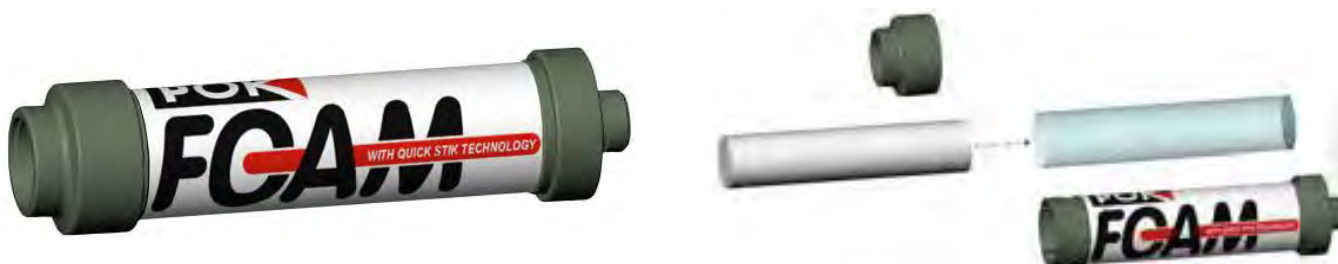


Figure 2. POK inline proportioner.

The concept of solidifying AFFF to eliminate stored water is not entirely new. In 1985, the 3M Corporation produced experimental solid AFFF pellets for the United States (U.S.) Air Force. These pellets were prepared based on a suspension of surfactants in high molecular weight poly (ethylene glycol) (PEG). The concept was the same: water was passed through the pellets to create foam solution. The dilution and fire performance of these pellets were tested by the Naval Research Laboratory (NRL) (Reference 1). The

MIL-SPEC fire test method was used to determine fire performance. The fires were extinguished using solutions prepared with the solid AFFF pellets. The solutions averaged slightly longer times to control and extinguish the fires when compared to 3 percent MIL-SPEC AFFF. Limitations regarding burnback performance and mixing were also identified. Because of the substantial savings in weight and space, it was recommended that improvements to the formulation be performed, or that a “super-concentrated” AFFF be developed which could be reconstituted with water. These efforts were not pursued. The 3M Corporation has subsequently ceased production of all AFFF.

3.2 Test Selection

There are two test standards/methods used to approve AFFF for marine applications that might directly apply to this investigation:

- MIL-F-24385F: “Specification, Fire Extinguishing Agent, Aqueous Film-Forming (AFFF) Liquid Concentrate, for Fresh Water and Sea Water” (Reference 2).
- Maritime Safety Committee/Circular (MSC/Circ.) 1312: “Revised Guidelines for the Performance and Testing Criteria, and Surveys of Foam Concentrates for Fixed Fire-Extinguishing Systems” (Reference 3).

MIL-F-24385F is the standard for approving AFFF used on military vessels including USCG cutters. MSC/Circ. 1312 is used for approving AFFF for use on commercial vessels. Both test standards are based on the extinguishment of small-to-medium size pan/pool fires with scaled-down AFFF application rates (flow rates). They also include a number of chemical property tests that were not included/assessed during this investigation (i.e., this investigation focused solely on the firefighting capabilities of the technology). The fire tests required by the two standards are summarized in Table 1.

Table 1. Approval test summary.

Parameter	MIL-F-24385F (Test 1)	MIL-F-24385F (Test 2)	MSC/Circ. 1312
Pan Fire Size (m^2 (ft^2))	2.6 (28)	4.6 (50)	4.5 (~50)
Pan Fire Shape	Round	Round	Square
Fuel	Unleaded gasoline	Unleaded gasoline	Heptane
AFFF Flow Rate (Lpm (gpm))	7.6 (2)	7.6 (2)	11.4 (3)
AFFF Discharge Time (sec)	90	90	600
Extinguishment Time (sec)	30	50	300
25% Burnback Time (min)	6	6	15

Conceptually, the approach is similar between the two standards. However, there are a number of differences including the test fuels, the AFFF application rates, and the performance requirements.

A correlation between the small-scale 2.6 m^2 (28 ft^2) MIL-SPEC test and large-scale performance has been demonstrated for handline applications (Reference 4). The MIL-SPEC test is more challenging than larger test areas in terms of time to achieve fire control. As a result, a MIL-SPEC-approved agent can meet large-scale pool extinguishment requirements at less than the recommended design application rates. This provides a factor of safety for AFFF which passes the MIL-SPEC tests. The MIL-SPEC 2.6 m^2 (28 ft^2) fire test was used as the primary method of assessment in this analysis of commercially available solid AFFF.



4 APPROACH

The approach for this investigation was intended to provide an indication of the solid AFFF system parameters required to meet both the military and commercial requirements as well as a metric for comparing solid AFFF with the currently used MIL-SPEC AFFF.

It was anticipated that the test program would include two phases/test series. Phase I was to consist of a parametric assessment of solid AFFF with the intent to produce extinguishment capabilities similar to that of the currently used MIL-SPEC AFFF. If the performance of the AFFF stick was equal to or reasonably close to the performance of MIL-SPEC AFFF, additional tests were to be conducted against a larger fire scenario. This would validate the Phase I results and demonstrate the capabilities of solid AFFF on a more representative scale.

During Phase I, the AFFF concentration and/or agent application rates were systematically increased in an attempt to demonstrate comparable performance between the AFFF stick and MIL-SPEC AFFF. The solutions were produced using combinations of one or two inline proportioners in series. Alternately, the solid stick was dissolved and mixed in known quantities of water to create various concentrations.

The 2.6 m² (28 ft²) pan fire in MIL-F-24385F was used as the basis of the parametric assessment. Two fuel types were used: gasoline, as specified in the MIL-SPEC; and marine diesel fuel (F76). The tests were conducted using the MIL-F-24385F test procedures (e.g., test timing, AFFF discharge duration, performance requirements, etc.). In several tests, a firefighting nozzle attached to the inline proportioner cartridge was used to combat the MIL-SPEC 2.6 m² (28 ft²) fire.

In several tests, the expansion and drainage characteristics of the AFFF stick were measured, along with the ability of the foam solution to form a film and seal vapors from a hydrocarbon fuel.

Tests were conducted in September - October, 2010 at the Chesapeake Beach Detachment (CBD) fire test facility of NRL.

5 MEASURES OF PERFORMANCE

5.1 Concentration

Foam is produced by mixing a liquid foam concentrate with water at the appropriate proportions, and then aerating and agitating the resulting solution to form the bubble structure. AFFF is available in concentrates of 1, 3, and 6 percent, where concentrate-to-water ratios of 1:99, 3:97, and 6:94, respectively, are used to create the foam solution. MIL-SPEC AFFF concentrates are either 3 or 6 percent. In special situations (e.g., on submarines), a commercially available 1 percent concentrate (non-MIL-SPEC) has been approved for use.

Concentration for solid AFFF was characterized by measuring the amount of solid material diluted in a known quantity of water. The resulting measure is weight per unit volume of water, g/L (lbs/gal). This “concentration” parameter was used in the previous U.S. Air Force/Navy assessment of solid AFFF.



5.2 Fire Extinguishment

The fundamental comparative measure of fire performance is the total time to extinguish the test fire, measured in seconds or minute. For the MIL-SPEC 2.6 m² (28 ft²) fire test, the fire must be extinguished in 30 seconds or less. The convention used in this report for time measurement is minutes:seconds. For example, a discharge time of 1 minute and 30 seconds was recorded as 1:30.

Application rate and application density are also measures used to assess AFFF extinguishing performance. Application rate is the flow rate of the nozzle divided by the fire test area, Lpm/m² (gpm/ft²). The application rate for the 2.6 m² (28 ft²) MIL-SPEC test is 2.9 Lpm/m² (0.071 gpm/ft²). For a constant fire area, extinguishment time should decrease (up to some limiting time) as application rate increases. This characteristic can be normalized (removing the time element) using extinguishment application density. This is the volume of foam required to extinguish a known area of fire, L/m² (gal/ft²). For the 2.6 m² (28 ft²) MIL-SPEC test, the maximum extinguishment density permitted is 1.5 L/m² (0.036 gal/ft²).

The application rate and density for the 4.6 m² (50 ft²) MIL-SPEC test are more challenging than the 2.6 m² (28 ft²) test, 1.63 Lpm/m² (0.04 gpm/ft²), and 1.5 L/m² (0.036 gal/ft²), respectively. Tests in this project did not proceed to this more challenging assessment.

Fuel affects fire extinguishment time, and associated application density. Most tests in this assessment were conducted with gasoline, as specified in the MIL-SPEC test. Several tests were conducted with a higher flashpoint fuel: marine diesel (F76). Generally, higher flashpoint fuels are easier to extinguish (requiring a lower application density) than low flashpoint fuels such as gasoline or heptane.

The term “knockdown” is also used to describe AFFF fire performance. This is based on a visual assessment of the fire being controlled before 100 percent extinguishment. This is sometimes described in terms of the amount of fire area extinguished; e.g., 50 percent knockdown indicates 50 percent of the fire area was extinguished.

5.3 Burnback and Ignition Resistance

Foam should provide some degree of ignition resistance when applied to an unignited fuel spill or to a fuel spill after a fire has been extinguished. This provides for ignition resistance and firefighter safety. Standard methodologies exist to characterize ignition resistance.

5.3.1 Burnback

Burnback is characterized in the MIL-SPEC by placing a burning pan within the fire area after the gasoline fire has been extinguished. Burnback is the time for the fuel surface to re-ignite and sustain a fire over a certain area. In the MIL-SPEC test, the AFFF used to extinguish the test fire must prevent burnback over 25 percent of the pan area (0.65m² (7.0 ft²) for the 2.6 m² (28 ft²) test) for a minimum of 6 minutes, after applying 11.4 L (3 gal) of AFFF.

5.3.2 Film Formation and Sealability

AFFF is formulated using hydrocarbon and fluorinated surfactants which create an aqueous film on fuel surfaces. This enhances the fuel vapor suppression characteristics of the applied foam blanket. As solution drains from the foam, a continuous aqueous layer is formed and maintained under the foam, creating an additional vapor barrier. This attribute is unique to AFFF among firefighting foams and provides better fire extinguishing performance.



The film formed by AFFF is characterized in the MIL-SPEC and MSC tests by a spreading coefficient test. This test demonstrates the ability of AFFF to “float” on a hydrocarbon fuel. Additionally, the MIL-SPEC includes a film formation and scalability test. Unfoamed aqueous solution is created on a hydrocarbon fuel surface (cyclohexane). After a 1-minute waiting period, a flame is passed over the sample. The AFFF must resist fuel surface ignition from this flame. This test was performed on several samples of the solid AFFF stick solution.

5.3.3 Expansion and Drainage

Foam expansion is the ratio between the volume of foam produced and the volume of solution used in its production. The foam drainage time (quarter life) is the time that it takes for 25 percent of the total liquid contained in the foam sample to drain from the foam. The MIL-SPEC requires a minimum expansion ratio of 5:1 and a minimum 25 percent drain time of 2:30 (2 minutes and 30 seconds).

No direct correlations between expansion, drainage, and fire performance have been established. There is a relationship between drainage and burnback. There appears to be a lower limit where AFFF becomes ineffective. This has not been quantified, but it is expected that poor fire performance occurs when the AFFF expansion is less than 2.5–3.0:1, and 25 percent drainage is difficult to measure (i.e., nearly instantaneous) (Reference 5). AFFF nozzle testing by the USCG supports this lower limit: foam expansion ratios as low as 4:1 were used to successfully control a fire when applied at the appropriate application rate (Reference 6).

Expansion and drainage tests were performed on selected solid AFFF stick solutions.

6 TEST FACILITIES, EQUIPMENT, AND INSTRUMENTATION

6.1 Test Facility

Tests were conducted in the large burn building at CBD of NRL. The building was approximately 15.2 m long x 15.2 m wide x 9.1 m tall (50 ft long x 50 ft wide x 30 ft tall). The fire pan was placed near the center of the building. There were louvers along the sides of the building to supply air to support combustion. There was an opening in the roof to allow the products of combustion to exit the building. An exhaust fan was activated to clear smoke; it was operated on low during the test and high after the test.

6.2 Fire Pans

All tests were conducted in the MIL-F-24385F 2.6 m² (28 ft²) pan. The round pan was made of 0.64 cm (0.25 inch) stainless steel and was 1.8 m (6 ft) in diameter and 10.2 cm (4 inch) deep. The pan was leveled prior to the start of testing.

The burnback pan was made of 3.1 mm (0.122 inch) stainless steel and was 0.3 m (1 ft) in diameter and 2.5 cm (1 inch) deep. There was a handle located on the top of the pan to allow it to be inserted and removed from the larger pan during the burnback portion of the test.

6.3 Fuel

Ten gallons of unleaded motor gasoline, in accordance with American Society for Testing and Materials (ASTM) D439 (Reference 7), is specified in the MIL-SPEC. Because most local fuel inventories were carrying ethanol-based products, E10 gasoline was used. NRL researchers report that no differences in performance have been observed using the E10 gasoline compared to unleaded motor gasoline.



Solid AFFF Technology Investigation

In order to observe extinguishing variations related to the test fuel, marine diesel fuel (F76) was used in several tests. This has a reported flashpoint on the order of 52–60 °C (125 - 140 °F).

6.4 AFFF

6.4.1 Liquid AFFF Concentrates

6.4.1.1 MIL-SPEC AFFF

Two baseline tests were performed with an approved MIL-SPEC AFFF concentrate, produced by Buckeye Fire Equipment Company. It was a 3 percent concentrate currently on the MIL-SPEC Qualified Products List (Buckeye 3 percent BFC-3MS AFFF Cage Code 57658 (Reference 8)).

6.4.1.2 UL Listed AFFF

In one test, a non-MIL-SPEC-approved AFFF was tested against the MIL-SPEC fire. Ansulite 1 percent, manufactured by Ansul, Inc., Marinette, WI, is a UL Listed foam (Reference 9), used in special circumstances onboard U.S. Navy submarines.

6.4.2 Solid AFFF

6.4.2.1 Solid AFFF Stick

The commercially available solid AFFF was manufactured by Buckeye exclusively for POK of North America. A Material Safety Data Sheet (MSDS) for the AFFF stick is provided in Appendix A. The packaging and manufacturer's data provides information on the solid AFFF stick. The stick is designed to be used in POK foam nozzles and proportioners with Quick Stik technology. The nominal weight of the stick was 550 grams \pm 25 grams (1.21 \pm 0.05 lb). It was reported to be manufactured in solid stick form using UL Listed ingredients. It was nominally 50 mm (dia.) x 250 mm long (2.0 x 9.8 inches). The stick has reported shelf life of 5 years (if stored in the original intact packing). It was recommended to be stored at temperatures from -18 ° to 35 °C (0 °F to 95 °F). Figure 3 shows the solid stick used in testing.



Figure 3. Commercially available solid AFFF stick, with protective wrapper (removed when in use).



Solid AFFF Technology Investigation

In accordance with the manufacturer's literature, the stick is designed to produce 1500 L (396 gal) of foam solution, depending on the water temperature. This equates to an average of 0.37 gram of solid material per liter of water (3.1×10^{-3} lbs/gal) to create foam solution.

Additionally, two experimental prototype stick formulations were provided by Buckeye as the experimentation proceeded. Four yellow-colored sticks (designated #1), numbered 1, 2, 3, and 4, and four blue-colored sticks (designated #2), numbered 5, 6, 7, and 8, were provided (see Figure 4). Some of these sticks had a 9.52 mm (3/8 in.) diameter hole drilled lengthwise through the center of the stick, presumably to increase the overall surface area available for dilution by the passing water.



Figure 4. Experimental prototype #2 blue solid AFFF stick.

6.4.2.2 3M Solid AFFF Pellets

In 1985, the 3M Company provided NRL with experimental solid AFFF pellets for testing as described in Reference 1. Some of these pellets were still on hand at the NRL CBD facility. They were tested for comparative purposes with the commercially available solid AFFF stick.

As described in the original test and evaluation report (Reference 1), the pellets measured 4.77 x 4.77 mm (0.188 x 0.188 in.) on average. The bulk (dry) density was 0.7 g/L (5.8×10^{-3} lbs/gal), while the full density (completely packed without air space) was 1.4 g/L (11.6×10^{-3} lbs/gal). The recommended foam solution utilized a ratio of 6 grams solid material to 1 liter of water (50.0×10^{-3} lbs/gal). This was subsequently increased to 8 g/L (66.6×10^{-3} lbs/gal). Like the solid stick, the pellets were designed to have water flow through them to create solution. Most of the prior testing was performed with the foam solutions premixed at 6 or 8 g/L (50.0×10^{-3} or 66.6×10^{-3} lbs/gal).

6.5 Creation of AFFF Solutions

As shown in the test reports referenced in the Qualified Products List (QPL) database (Reference 8), foam solutions made with salt water have better fire extinguishing capabilities than those made with fresh water solutions. As such, all of the AFFF solutions in these tests were produced using fresh water. The following sections describe how the test solutions were prepared.



6.5.1 Solid AFFF Stick

Foam solution was created using three different methods, two which created a premixed solution for use in the MIL-SPEC discharge apparatus, and one using the inline cartridge to create a foam solution directly for discharging on to the fire. The first two methods were designated as premixed solution. One technique to create premix used the inline proportioning cartridge through which water was discharged to create and store foam solution. For very high concentrations, sticks were liquefied in hot water, and then added to a known quantity of water to form the desired foam solution concentration.

6.5.1.1 Inline Premixed Solutions

It was assumed that the concentration of the foam solution created from the inline device would decrease with time (because there would be less stick surface area as the stick became smaller with dilution). Based on the recommended 1500 L (396 gal) of foam solution per stick, a pair of large containers was arranged to capture the solution as it was created using the inline device as shown in Figure 5. The intent was to discharge nominally 360 Lpm (95 gpm) across the stick, the discharge rate of a standard USCG hose nozzle. A pump rated at 379 Lpm (100 gpm) discharging at 6.6 bar (95 psi) was used, taking suction from the on-site water supply. The water supply had a static pressure of 4.5 bar (65 psi). Water was discharged through one or two of the clear proportioning devices, depending on the concentration desired. At the upstream end of the proportioner, a 14.3 mm (0.564 in.) orifice plate was installed to approximate the 360 Lpm/6.9 bar (95 gpm/100 psi) flow of a standard USCG vari-nozzle. Flow rate was verified by timed measurement of liquid into storage containers (intermediate bulk containers (IBCs)) having known dimensions. Due to limitations of the pump and hose/proportioner friction loss, the typical flow rate was on the order of 246 - 322 Lpm (65 - 85 gpm) at 5.2–6.2 bar (75 - 90 psi), depending on the time of the discharge and the proportioning arrangement (one or two sticks).

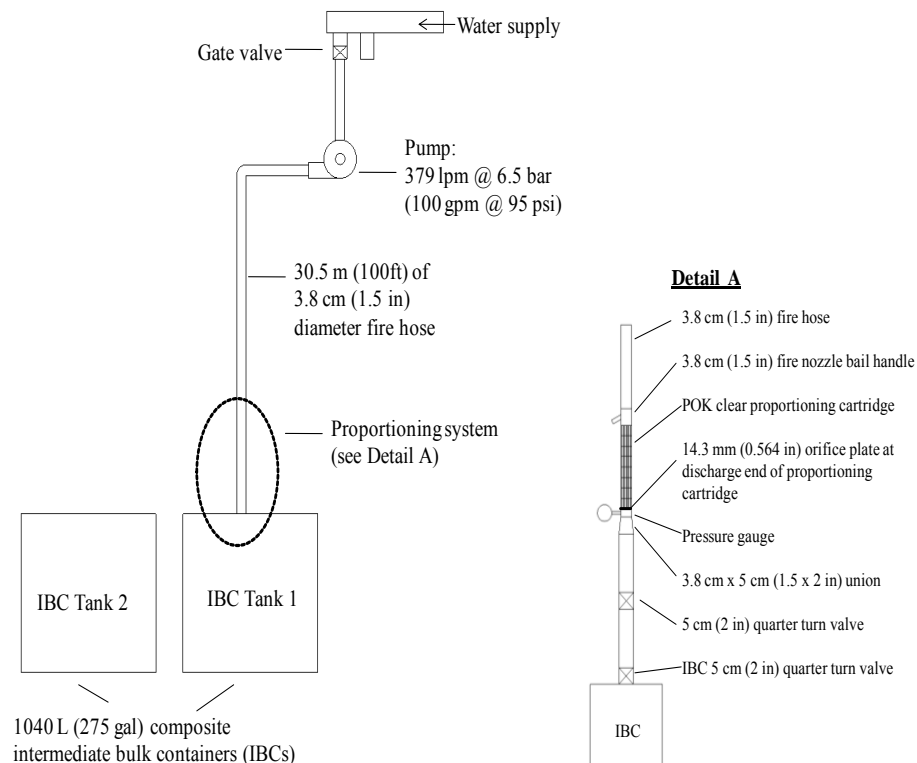


Figure 5. Creation of foam premix solution using inline solid AFFF proportioners.

To create the average 0.27 g/L (2.2×10^{-3} lbs/gal) premix, a single stick was used. The initial 25 percent of the flow (about 378 L (100 gal)) was stored in IBC #1. The next 50 percent of flow (about 757 L (200 gal)) was stored in IBC #2. The final 25 percent was stored in IBC #1. The intent was to average the concentration between the two storage containers. The concentration was determined by subtracting the final weight of the solid stick from its initial weight, divided by the known volume of solution created.

An attempt to measure concentration was made using a digital refractometer, but the results did not conform to the straight line slope formula used to measure liquid concentrates. This inability to apply refractive index data to measure solid solutions was observed in the previous 3M solid AFFF tests (Reference 1).

The solution from IBC #1 was used in the first two fire tests. Afterwards, the remaining solution from IBC #1 was stored in IBC #2. A stronger solution was prepared in IBC #1 by using two solid sticks inline. This arrangement resulted in a foam concentration of 0.71 g/L (5.9×10^{-3} lbs/gal).

6.5.1.2 High Concentration Premix

Premix solution of 3.2 g/L (26.6×10^{-3} lbs/gal) were created by dissolving sticks (of known weight) in 18.9 L (5 gal) of warm water. This “concentrate” was then added to a known volume of water to create a higher concentration premix.

6.5.1.3 Direct Inline Proportioning Discharge

In several tests, the solid AFFF solution was created and discharged directly on the fire using the inline proportioned (with stick) with a firefighting nozzle. Because it was known at this point in testing that a single stick concentration (on the order of 0.27 g/L (2.2×10^{-3} lbs/gal)) would likely be ineffective, two proportioners (with sticks) were used.

A POK 20/60 Wildland Tip nozzle was used. The unit could not be used at high pressure/flow because the resulting stream reach was too great for the fire test facility. The water supply was arranged to provide approximately 0.69 bar (10 psi) nozzle pressure with the two inline devices installed. The resulting water flow was 103.7 Lpm (27.4 gpm). The nozzle arrangement is shown in Figure 6. This flow rate was used in the inline proportioner tests, and resulted in a foam solution concentration of 0.87 g/L (7.2×10^{-3} lbs/gal). This was determined based on the known amount of flow and pre-and post-test weight of the solid sticks.

6.5.2 Solid AFFF Pellets

The 3M solid AFFF pellet foam solution was created using the inline premix or direct inline proportioning methods previously described for the commercial AFFF stick. For the premix solution, a concentration of 8 g/L (66.6×10^{-3} lbs/gal) (as used in the 1985 tests) was prepared by dissolving the pellets in a known quantity of water. In the direct, inline proportioner tests, one proportioning cartridge was filled with pellets. A concentration of 3.8 g/L (31.6×10^{-3} lbs/gal) was achieved at a flow rate of 104 Lpm (27.5 gpm).

6.5.3 MIL-SPEC and Commercial Liquid AFFF

The MIL-SPEC and commercial liquid AFFF concentrate was premixed with water in known ratios, 1:99 for the 1 percent commercial AFFF and 3:97 for the 3 percent MIL-SPEC AFFF, to create the test solutions.





Figure 6. Direct inline proportioning and nozzle setup.

6.6 Fire Extinguishing System

All fires were manually extinguished using a gentle, direct application of foam solution to the fuel surface. The air-aspirating fan tip nozzle described in MIL-F-24385F was used to apply the foam to the fire. There was an orifice insert in the nozzle that regulated the flow through the nozzle. The MIL-F-24385F orifice was designed to flow 7.6 Lpm at 7 bar (2 gpm at 100 psi). Additional inserts were made which produced flows of 15.9 and 29.9 Lpm (4.2 and 7.9 gpm) at the nominal 7 bar (100 psi) discharge system pressure. In the tests with the experimental prototype sticks, the highest flow drifted up to 32.1 Lpm (8.5 gpm). The nozzle flow rates were measured with water before each test using a timed discharge into a container of known dimensions/volume.

6.7 Instrumentation and Photography

The instrumentation used during the tests included:

- A digital scale to weigh the solid AFFF stick before and after the various solutions were made and to measure cylinder weights in the expansion and drainage tests.
- A digital refractometer (MISCO PA202) which was attempted to be used to determine the AFFF concentration of the foam solutions.
- The agent storage tank which was equipped with a pressure gage to set/monitor the extinguishing system pressure during each test.
- A video camera to visually document the events of each test.

Visual observations were made to determine the extinguishment and burnback times.

6.8 Test Parameters and Procedures

The test-specific parameters and procedures are described in the following sections. The standard test data sheet/check list used for each test is shown in Appendix B.



6.8.1 MIL-F-24385F-based Fire Test and Burnback Parameters and Procedures

Prior to the start of the test, the foam solution was prepared and the fire suppression system pressurized. Approximately 12 mm (0.5 inch) of water was added to the pan to provide a level surface. The test was conducted using 38 L (10 gal) of E10 gasoline. The fuel was ignited in less than 30 seconds after it was dumped into the pan. After a 10-second preburn time, the attack on the fire was initiated and AFFF solution was discharged into the pan. The extinguishing time was recorded, or the time when agent discharge was terminated. For tests where the fire was extinguished, foam application continued for a total of 90 seconds. Within 60 seconds of the completion of foam application, the burnback pan (previously ignited) containing 3.78 L (1 gal) of E10 gasoline was placed in the center of the 2.6 m² (28 ft²) pan and a timer started. When it appeared that the fire had become established around the perimeter of the burnback pan, the pan was removed. Once 25 percent of the 2.6 m² (28 ft²) pan was involved, the time was noted/recorded and the test terminated. MIL-F-24385F requires that the initial fire must be extinguished in 30 seconds or less and the 25 percent burnback time must be greater than 6 minutes.

6.8.2 MIL-F-24385F-based Foam Quality Parameters and Procedures

In selected tests, foam quality was assessed. This included expansion and 25 percent drainage time, and film and seal testing. These tests were performed in accordance with the MIL-SPEC.

Foam expansion and 25 percent drainage for selected test samples was assessed using the apparatus and methodology in National Fire Protection Association (NFPA) 412, Method A (Reference 10) as referenced in the MIL-SPEC. This apparatus included a metal collection slider with positions for two 1000 mL (0.26 gal) graduated cylinders. The foam samples were collected using these graduated cylinders, which were cut off at the 1000 mL (0.26 gal) mark to ensure a sample of a fixed volume.

The empty weight of the foam sample containers were recorded to the nearest gram. They were positioned below the foam collector so that the foam hitting the collector flowed into the containers. The MIL-SPEC 7.6 Lpm (2 gpm) foam nozzle was adjusted to its normal operating pressure, and then moved so as to discharge foam onto the foam sample collector. As soon as the foam sample containers were completely filled with foam, the discharge nozzle was shut off and the timing of the 25 percent drainage started.

Excess foam was struck off the top of the foam containers using a straight edge, and any remaining foam wiped from the outside surface of the containers. The total weight of each foam sample including the container was determined, and the weight of the foam sample was determined by subtracting the weight of the empty container from the weight of the container filled with the foam. The weight of the foam sample in grams was divided by 4 to obtain the equivalent 25 percent drainage volume in milliliters.

The foam sample container was then placed on a level surface at a convenient height. At 30-second intervals, the level of accumulated solution in the bottom of each cylinder was noted and recorded. The drainage time versus the volume relationship was recorded until the 25 percent volume was exceeded. The 25 percent drainage time was then interpolated from the data.

The expansion of the foam was calculated by the following equation:

$$\text{Expansion} = \frac{1000 \text{ mL}}{(\text{full weight}) - (\text{empty weight in grams})}$$



The expansion and drainage time was recorded as the average of the two samples. The minimum permitted expansion and 25 percent drainage time permitted in the MIL-SPEC are 5.0:1 and 2.5 minutes, respectively.

The MIL-SPEC film formation and sealability test was also performed for selected test solutions. A 1000 mL stainless steel cylinder was fitted with an inverted mesh cone. After 400 mL of water and 200 mL of cyclohexane were placed in the cylinder, 200 mL of foam from the 7.6 Lpm (2.0 gpm) nozzle was placed onto the fuel surface. The inverted cone was pushed down into the cylinder, which pushed most of the foam aside but allowed the film-producing liquid to creep through the mesh openings. A foam-free surface was created by scooping away the remaining residual foam from the center of the cone. After waiting for a 1-minute period, a pilot flame (25.4 mm, 1 in. long from a hand-held propane cylinder with a capillary tube) was passed over the fuel surface at a height of about 12.7 mm (0.5 in.). No sustained ignition was permitted.

7 RESULTS OF MIL SPEC AFFF BASELINE TESTS

Two tests were performed as a baseline with MIL-SPEC AFFF. The results are shown in Table 2. The first test exceeded the 30-second extinguishment criterion by 3 seconds. The second test, where the fire was extinguished in 28 seconds, passed the MIL-SPEC criterion. Expansion and 25 percent drain time also passed the MIL-SPEC requirements.

Table 2. Results of baseline MIL-SPEC AFFF tests.

Test	Agent	Extinguishment Time (min:sec)	Burnback Time (min:sec)	Expansion	25% Drain Time (min:sec)
BB1	MIL-SPEC 3% AFFF Concentrate	0:33	Not performed	Not performed	Not performed
BB2	MIL-SPEC 3% AFFF Concentrate	0:28	12:11	8.2 average	4:45 average

8 RESULTS OF COMMERCIALY AVAILABLE SOLID AFFF STICK

Table 3 summarizes the results of testing with the commercially available solid AFFF stick. During tests where there was no substantial knockdown or extinguishment, the time the firefighter could attack the fire was generally on the order of 1 minute. Radiant heat then caused the firefighter to back off, and the fire was extinguished using a backup 7.8 Lpm (2.1 gpm) nozzle with MIL-SPEC AFFF.

8.1 Initial Tests of Solid AFFF Stick

The test fire using the 7.6 Lpm (2 gpm) nozzle was not extinguished using the recommended concentration of 0.27 g/L (2.2×10^{-3} lbs/gal) (STIK-1). The firefighter had to back off after 42 seconds of attack. The flow rate was more than doubled in STIK-2 (15.9 Lpm (4.2 gpm)), but there was no extinguishment or knockdown after 50 seconds of discharge.



8.2 Solid AFFF Premix Solution

During the following tests, the concentration and nozzle flow rates were substantially increased in an attempt to achieve extinguishment. The solid AFFF was also evaluated using lower volatility marine diesel fuel.

The premix solution was created using either the inline proportioning method (STIK-3 and STIK-4), or the premix dilution method (STIK-5 through STIK-9).

In STIK-2 through STIK-8, the flow rate of the MIL-SPEC nozzle remained constant at 15.9 Lpm (4.2 gpm). The corresponding application rate was 6.1 Lpm/m^2 (0.15 gpm/ft^2) compared to the MIL-SPEC application rate of 2.9 Lpm/m^2 (0.071 gpm/ft^2). STIK-3 was a test of an increased premix concentration to 0.71 g/L ($5.9 \times 10^{-3} \text{ lbs/gal}$), compared to STIK-2 at the recommended concentration. No knockdown or extinguishment was observed after 50 seconds of agent discharge. This test was repeated in STIK-4, with F76 marine diesel fuel substituted for gasoline. There was some knockdown of the fire, but there was flashback and no extinguishment after 65 seconds of agent discharge.

Because there appeared to be some promise of extinguishment of marine diesel fuel, STIK-5 was performed with F76 marine diesel fuel with a substantially increased premix AFFF concentration of 3.2 g/L ($26.6 \times 10^{-3} \text{ lbs/gal}$). This was more than 10 times the recommended concentration of 0.27 g/L ($2.2 \times 10^{-3} \text{ lbs/gal}$). This concentration was subsequently used in STIK-6, STIK-7, and STIK-9. There was evidence of knockdown about 1 minute into the test, when the firefighter changed tactics and discharged agent at a low level. This was achieved by the firefighter crouching low, keeping the nozzle level just above the fuel surface. Using this tactic, the fire was ultimately extinguished after 2 minutes and 16 seconds of agent discharge. Given the success of this test, the low level tactic was used from the start in STIK-6, using the same premix concentration against the marine diesel fuel fire. The fire was extinguished in 57 seconds. This resulted in extinguishment density of 6.1 L/m^2 (0.15 gal/ft^2), compared to the MIL-SPEC requirement (against gasoline) of 1.5 L/m^2 (0.036 gal/ft^2). Ultimately, these were the only two tests where the solid AFFF stick material was able to extinguish the test fire.



Solid AFFF Technology Investigation

Table 3. Results of 2.6 m² (28 ft²) fire tests of commercially available solid AFFF stick.

Test	Fuel	Agent	Concentration g/L (lbs/gal, x 10 ⁻³)	Flow Rate Lpm (gpm)	Discharge Time (min:sec)	Results
STIK-1	MOGAS *	Solid AFFF	0.27 (2.2)	7.6 (2)	0:42	No knockdown/no extinguishment
STIK-2	MOGAS	Solid AFFF	0.27 (2.2)	15.9 (4.5)	0:50	Repeat Test 1 with twice the flow rate: no knockdown/no extinguishment
STIK-3	MOGAS	Solid AFFF	0.71 (5.9)	15.9 (4.5)	0:50	Repeat Test 2 with higher concentration: no knockdown/no extinguishment, some foam was evident on fuel surface
STIK-4	F76	Solid AFFF	0.71 (5.9)	15.9 (4.5)	1:05	Repeat Test 3 using F76 as fuel: some knockdown @ 21 seconds, then flashback. No extinguishment
STIK-5	F76	Solid AFFF	3.2 (26.6)	15.9 (4.5)	2:16	Repeat Test 4 with much higher concentration; tactics changed at 1:26 to low level application. Tactics plus higher concentration resulted in extinguishment
STIK-6	F76	Solid AFFF	3.2 (26.6)	15.9 (4.5)	0:57	Repeat Test 5 using low level tactic: extinguished at 0:57
STIK-7	F76	Water		15.9 (4.5)	1:12	Repeat Test 6 with water: no knockdown, no extinguishment
STIK-8	MOGAS	Solid AFFF	3.2 (26.6)	15.9 (4.5)	1:00	Repeat Test 6 with gasoline: no knockdown/no extinguishment, a little foam observed on fuel surface
STIK-9	MOGAS	Solid AFFF	3.2 (26.6)	29.9 (7.9)	1:02	Repeat Test 8 with much higher flow rate: same results as Test 8, no knockdown/no extinguishment, a little foam observed on fuel surface
STIK-10	MOGAS	Solid AFFF – 2 stiks inline	0.87 (7.2)	104 (27.4)	1:11	Two stiks inline with 27.4 gpm nozzle: no knockdown/no extinguishment, some effect at 0:55; failed film and seal test
STIK-14	MOGAS	Solid AFFF	3.2 (26.6)	7.6 (2)	0:47	Repeat Test 9: no knockdown/no extinguishment at 0:47; failed film and seal test

Note: All tests conducted with AFFF solution premixed/pre-prepared, except Test 10 which used two stiks inline.

*Motor gas (commercially available gasoline)



To verify that the solid AFFF was contributing to extinguishment, STIK-5 and STIK-6 were repeated in STIK-7, using water discharged at the same 15.9 Lpm (4.2 gpm) flow rate. There was no fire knockdown or extinguishment after 72 seconds of water application.

To determine if tactics were the key variable in the success of STIK-5 and STIK-6, these tests were repeated using gasoline as the test fuel in STIK-8. The low-level tactic was used. While a little foam agent was observed on the fuel surface, it was quickly destroyed by the fire. There was no knockdown or extinguishment after 1 minute of agent application. This test was repeated in STIK-14 at the 7.6 Lpm (2 gpm) MIL-SPEC discharge rate. There was no knockdown or extinguishment. This indicated the fuel was the primary variable affecting extinguishment performance, not the tactics.

As a final test of premixed solid AFFF solution, STIK-9 was performed using a rate of 29.9 Lpm (7.9 gpm) through the MIL-SPEC test nozzle. The low-level application tactic was used. The results were similar to STIK-8, with no knockdown or extinguishment after 62 seconds of foam discharge. Test EB-2 (see Section 11) was a repeat of STIK-9, with similar results.

8.3 Solid AFFF Inline Proportioning Test

The performance of the solid AFFF stick using the inline proportioner was evaluated in STIK-10 (Table 3). Based on the earlier results, two inline proportioners were used to achieve a higher than recommended concentration, 0.87 g/L (7.2×10^{-3} lbs/gal).

An actual firefighting nozzle was used, the POK Wildland 20/60 nozzle. The discharge rate was 104 Lpm (27.5 gpm), more than 10 times the MIL-SPEC nozzle flow rate of 7.6 Lpm (2 gpm). The firefighter stood off approximately 9.1 m (30 ft) and lobbed the agent into the test pan. This resulted in some overspray, but it was estimated that at least 75 percent of the flow was discharged onto the fuel surface. There was some effect evident at 55 seconds, but no significant knockdown. At 71 seconds, the agent/fuel began to overflow the pan and the test was terminated with no fire extinguishment.

9 RESULTS OF EXPERIMENTAL PROTOTYPE SOLID AFFF STICK

Two experimental prototype sticks were provided by Buckeye: #1 Yellow sticks (numbered 1, 2, 3, 4) and #2 Blue sticks (numbered 5, 6, 7, 8). Tests were conducted as shown in Table 4. In STIK-16 E2, a premix solution was prepared using blue stick #6 with a resulting concentration of 3.2 g/L (26.6×10^{-3} lbs/gal). With a nozzle flow rate of 32.2 Lpm (8.5 gpm) through the MIL-SPEC nozzle, this test was analogous to STIK-9 with the commercial stick. The results were the same; there was no knockdown or extinguishment after 75 seconds of agent application. This test was repeated with experimental yellow stick #2 (STIK-17 E1), again, with the same results.



Solid AFFF Technology Investigation

Table 4. Results of 2.6 m² (28 ft²) fire tests of experimental prototype solid AFFF sticks.

Test	Fuel	Agent	Concentration g/L (lbs/gal, x 10 ⁻³)	Flow Rate Lpm (gpm)	Discharge Time (min:sec)	Results
STIK-16 E1	MOGAS	Solid AFFF Experimental #2	3.2 (26.6)	32.1 (8.5)	1:15	No knockdown, no extinguishment
STIK-17 E2	MOGAS	Solid AFFF Experimental #1	3.2 (26.6)	32.1 (8.5)	1:32	No knockdown, no extinguishment
STIK-18 E3	MOGAS	Solid AFFF – 2 Experimental Sticks #7 & #8 inline	1.5 (12.5)	104 (27.4)	1:51	20% control at 0:58; 40% control at 1:13 through completion of discharge



In STIK-18 E2, experimental blue sticks #7 and #8 were placed inline with a 104 Lpm (27.5 gpm) handline nozzle to compare with STIK-10. The resulting concentration was 1.5 g/L (12.5×10^{-3} lbs/gal). The results were slightly better than in STIK-10; the experimental sticks achieved approximately 20 percent control of the fire area in 58 seconds and 40 percent control in 73 seconds through the end of discharge at 1 minute 51 seconds. The test was terminated with no extinguishment.

10 RESULTS OF TESTS WITH 3M SOLID AFFF PELLETS

Solid AFFF pellets manufactured by the 3M Company, previously tested in 1985, were found in storage at NRL CBD. Tests STIK-11 through STIK-13, STIK-15, and EB-1 were performed with solid AFFF agent, as shown in Table 5 and Table 6.

In STIK-11, the solid pellets were dissolved in a premix at 8 g/L (66.6×10^{-3} lbs/gal) and applied using the MIL-SPEC 7.6 Lpm (2 gpm) nozzle. The fire almost met the MIL-SPEC criterion, with extinguishment at 31 seconds. This was repeated in STIK-13, with the same results. Burnback and film and seal tests were also performed (see Section 12).

STIK-12 was a repeat of STIK-10, where AFFF was discharged at 104 Lpm (27.4 gpm) nozzle flow with solution created from the inline proportioner. The 3M solid was proportioned at 3.8 g/L (31.6×10^{-3} lbs/gal), compared to 0.87 g/L (7.2×10^{-3} lbs/gal) in the commercial solid stick test. The 3M pellets extinguished the fire in 32 seconds, where the commercial stick failed to extinguish the fire. For similar concentrations (3.2 g/L, STIK-8, STIK-9), the commercial stick failed to extinguish the fire. EB-1 (Table 6) was a repeat of STIK-12, with a slightly better extinguishment time (27 seconds).

The 3M solid pellets using one inline cartridge were tested against a marine diesel fire (STIK-15). After a 7 second application of foam, the fire quickly was extinguished. This shows how much easier a marine diesel fire is to extinguish compared to a gasoline fire (STIK-12).

11 RESULTS OF SHIPBUILDER TESTS

A U.S. Navy shipbuilder was on-site for a day of testing. The results are summarized in Table 6. These personnel observed tests with the commercially available solid AFFF stick (EB-2, a repeat of STIK-9), the 3M solid AFFF pellets (EB-1, a repeat of STIK-12), and a commercially available 1 percent concentration solution (EB-3). In EB-3, the commercial 1 percent AFFF extinguished the fire in 52 seconds, 22 seconds greater than that permitted in the MIL-SPEC.



Solid AFFF Technology Investigation

Table 5. Results of 2.6 m² (28 ft²) fire tests of 3M solid AFFF pellets.

Test	Fuel	Agent	Concentration g/L (lbs/gal, x 10 ⁻³)	Flow Rate Lpm (gpm)	Discharge Time (min:sec)	Results
STIK-11	MOGAS	Solid AFFF-3M	8 (66.6)	7.6 (2)	0:31	50% knockdown at 0:20, extinguishment at 0:31
STIK-12	MOGAS	Solid AFFF-3M proportioned inline	3.8 (31.6)	104 (27.5)	0:32	Knockdown at 0:23, extinguishment at 0:32
STIK-13	MOGAS	Solid AFFF-3M	8 (66.6)	7.6 (2)	0:31	50% knockdown at 0:20, extinguishment at 0:31
STIK-15	F76	Solid AFFF-3M inline	7.7 (64)	104 (27.5)	0:07	3M Solid AFFF in an inline cartridge-agent discharged for 7 seconds, fire knocked down and extinguished 6 seconds later (13 seconds extinguishment time)

Table 6. Results of shipbuilder demonstration tests.

Test	Fuel	Agent	Concentration g/L (lbs/gal, x 10 ⁻³)	Flow Rate Lpm (gpm)	Discharge Time (min:sec)	Results
EB-1	MOGAS	Solid AFFF-3M proportioned inline	3.8 (31.6)	104 (27.5)	1:30	Knockdown at 0:21, extinguishment at 0:27 25% burnback @ 7:20
EB-2	MOGAS	Solid AFFF	3.2 (26.6)	29.9 (7.9)	0:46	No knockdown/no extinguishment
EB-3	MOGAS	Ansulite 1%	1% Solution	7.6 (2)	1:30	Knockdown at 0:40, extinguishment at 0:52 25% burnback @ 4:30, 50% @ 4:50



12 RESULTS OF EXPANSION, DRAINAGE, BURNBACK, AND FILM AND SEAL TESTS

The results of foam quality tests are shown in Table 7. This includes the MIL-SPEC requirements.

Table 7. Results of foam quality tests.

Expansion and Drainage	Concentration, g/L (lbs/gal x 10 ⁻³)	Expansion Ratio	25% Drainage Time (min:sec)
MIL-SPEC Requirements	3 or 6% liquid	5:0:1	2:30
BB2	3% MIL-SPEC liquid	8.2:1	4:45
STIK-1 pretest sample	0.27 (2.2)	2.0:1	< 1:00
STIK-17 E1	3.2 (26.6)	4.8:1	≈ 1:50
STIK-13	3M solid pellets-8 (66.6)	8.2:1	4:20
Burnback		Time (min:sec)	
MIL-SPEC Requirements	3 or 6% liquid	≥ 6:00	
BB2	3% MIL-SPEC liquid	12:11	
Commercial STICK	Various	No tests performed	
STIK-11	3M solid pellets-8 (66.6)	9:19 ¹	
Film and Seal		Pass/Fail	
MIL-SPEC Requirements	3 or 6% liquid	No ignition for 1 minute flame exposure	
STIK-10	0.87 (7.2)	Fail	
STIK-14	3.2 (26.6)	Fail	
STIK-17 E1	3.2 (26.6)	Fail	
STIK-13	3M solid pellets-8 (66.6)	Pass	

¹Poor burnback technique: the burnback pan was removed prematurely, so the fire in the center of the fire pan was agitated to keep the ignition area from resealing.

In all of the situations tested, the commercially available solid AFFF failed the foam quality tests. At 0.27 g/L (2.2 x 10⁻³ lbs/gal), expansion was 2.0 and drainage was less than 1 minute. The #2 Blue experimental prototype at 3.2 g/L (26.6 x 10⁻³ lbs/gal) had somewhat better expansion and drainage, 4.8 and 1:50, respectively, but MIL-SPEC requirements were not met.

The commercial solid AFFF stick failed the film and seal test, indicating that an aqueous film was not being formed at the concentrations tested. No burnback tests were conducted because of its poor fire extinguishing performance (i.e., the test fires were never extinguished).

The 3M solid AFFF pellets passed the expansion, drainage, and burnback tests at 8.0 g/L (66.6 x 10⁻³ lbs/gal) and the film and seal test at 3.2 g/L (26.6 x 10⁻³ lbs/gal) concentrations.



13 CONCLUSIONS AND DISCUSSION

Based upon the test results reported herein, the currently available solid stick AFFF technology is not a suitable replacement for MIL-SPEC AFFF liquid concentrate. The results of the testing were disappointing, particularly given the potential weight and space advantages that might result from implementation of this technology. It was anticipated that the investigation would focus on the effects of discharge time with respect to concentration. As the stick eroded, it was anticipated that fire performance might degrade as less active ingredients were proportioned with water. Successful formulations could then be applied to scaled-up 4.6 m² (50 ft²) or larger fire areas.

Instead, the effort became focused on whether any reasonable concentration could be achieved from the commercially available or experimental prototype sticks which would control/extinguish a hydrocarbon fire. Unfortunately, even with more than 10 times the recommended concentration, plus 10 times the MIL-SPEC application rate, the commercially available stick was ineffective on the MIL-SPEC gasoline fire. One experimental stick appeared to be slightly better, but could only partly control the MIL-SPEC fire at a high application rate. This might be attributed to better erosion characteristics with the experimental stick. It had a concentration of 1.5 g/L (12.4 x 10⁻³ lbs/gal) (STIK-18 E2) compared to 0.87 g/L (7.2 x 10⁻³ lbs/gal) (STIK-10) at the same flow rate. As a result, no larger-scale tests, as planned, were performed.

The poor performance of the commercial solid stick was attributed to two factors: the effective concentrations, and, the base AFFF formulation. Using the intended method of direct, inline proportioning, a concentration of 0.27 g/L (2.2 x 10⁻³ lbs/gal) was obtained for a flow rate on the order of 280 - 322 Lpm (74 - 85 gpm) (STIK-1 and STIK-2). For two sticks inline, concentrations of 0.71 g/L (5.9 x 10⁻³ lbs/gal) (STIK-3 and STIK-4) and 0.87 g/L (7.2 x 10⁻³ lbs/gal) (STIK-10) were obtained for flow rates of 242 Lpm (64 gpm) and 104 Lpm (27.4 gpm), respectively. Tests with the higher flashpoint F76 marine diesel fuel indicated that an order of magnitude increase in concentration was required to approach some level of fire control/extinguishment.

The observation that the commercial stick, as provided, does not provide sufficient active agent is supported by the results of the previous 3M solid AFFF tests. There, 6 - 8 g/L (50.0 - 66.6 x 10⁻³ lbs/gal) concentration was needed to approach MIL-SPEC fire performance.

The second attribute affecting performance was the fluorosurfactant makeup of the agent. It was reported to be manufactured from UL Listed ingredients. The UL fire test method is less stringent than the MIL-SPEC, so UL Listed AFFF agents may not perform as well as those included on the MIL-SPEC qualified products list (Reference 11). For example, the UL AFFF minimum extinguishment application density is 4.9 L/m² (0.12 gal/ft²), which is nearly three times the minimum MIL-SPEC requirement.

This performance difference was evident in the test of the UL Listed 1 percent agent (EB-3), where the extinguishment time of 52 seconds was nearly double the permitted 30 seconds. Use of non-MIL-SPEC fluorosurfactant formulations might readily be expected to require longer extinguishment times.

Whether a factor of concentration, agent fluorosurfactant make-up, or overall agent constituents (including hydrocarbon surfactants for foam stability), the foam quality tests provided data which supported the conclusion that the foam created from the solid stick was of poor quality. The solid stick failed all expansion, drainage, and film formation tests. Although not performed, the spreading coefficient test with solid AFFF would very likely have failed. The poor quality of the foam was visually evident when it was



Solid AFFF Technology Investigation

sprayed onto the test facility floor, using the MIL-SPEC aerating nozzle (Figure 7). Nearly instantaneously, the solid foam collapsed and had no persistence. This contrasts with the MIL-SPEC foam which was persistent and collapsed/drained only after a period of time. Because the solid AFFF did not form a film, its lack of success in the MIL-SPEC test is understandable. Figure 8 shows the difference in fire control between AFFF made from MIL-SPEC qualified concentrate and the solid AFFF, at approximately 20 seconds into agent application.



Figure 7. Aerated MIL-SPEC AFFF compared to solid AFFF.

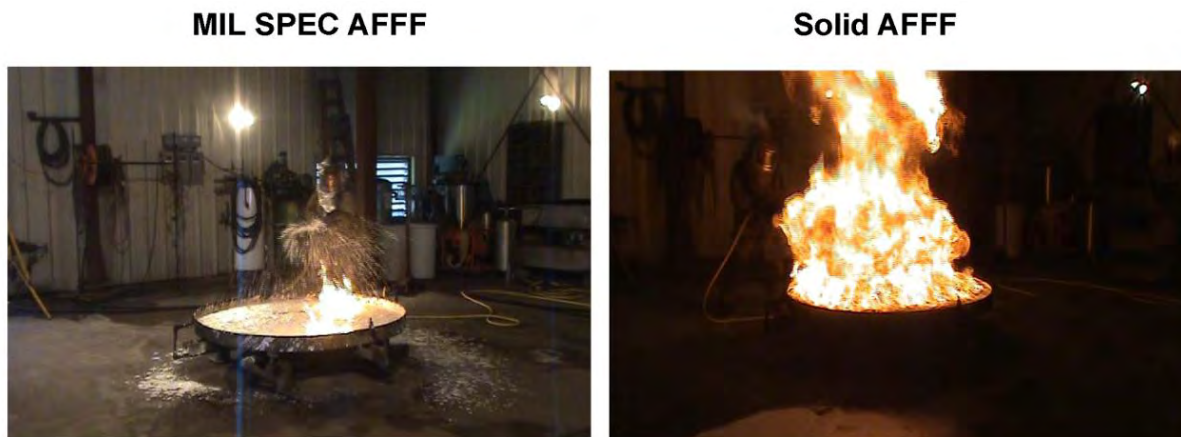


Figure 8. Comparison of fire knockdown between MIL-SPEC AFFF and commercially available solid AFFF.

The results of this test series are not altogether discouraging. Tests with the old 3M solid pellet AFFF (STIK-11, STIK-13, EB-1) show that it can provide performance nearly equivalent to MIL-SPEC AFFF (Figure 9). The original material was not adopted by the U.S. Air Force because it did not consistently pass the strict MIL-SPEC requirements for extinguishment and burnback. There were also unanswered questions about the design of large-volume solid cartridges for use on aircraft crash rescue vehicles.



MIL SPEC AFFF



Solid Pellets



Figure 9. Comparison of fire knockdown between MIL-SPEC AFFF and 3M solid pellet AFFF.

3M has exited the firefighting foam market because of environmental restrictions related to its electrochemical fluorination production method. This foam and its degradation products are considered persistent, bioaccumulative, and toxic. Further environmental restrictions are being applied to AFFF currently manufactured using the telomerization process. Long carbon chain molecules are being eliminated. The new formulations are expected to undergo UL and MIL-SPEC testing shortly. As a result of these formulation changes, it will be a challenge to maintain the same or similar firefighting performance as established by the MIL-SPEC.

The impact of these evolving changes to AFFF formulations was evaluated in an analysis prepared by the U.S. Navy (Reference 12). A framework for determining the required fire extinguishment and burnback performance of firefighting foam on Class B fire scenarios encountered by the Navy was established. Recognizing that MIL-SPEC AFFF provided a high degree of performance and associated factor of safety, the analysis attempted to answer the question, “How good is good enough?” Fire scenarios were prioritized, from those requiring the highest level of protection (Priority 1, such as a fire exposing ordnance on an aircraft carrier flight deck) to a lower priority (Priority 4, where there was no imminent ordnance or life safety threat, only structural damage). Scenarios similar to those encountered on USCG ships included:

- Ship helicopter flight deck: Priority 2, similar to an aircraft carrier flight deck, lower potential for multi-craft incident, lower parking density, and lower amount of ordnance.
- Machinery spaces: Priority 3, high value asset, no ordnance exposure, bilge AFFF has minimal impact on life safety due to presence of other total flooding agents.
- Single helicopter hangar on small ships: Priority 4, minimal ordnance, negligible life safety threat.

This framework indicates that a solid AFFF technology, which almost but does not quite meet the performance of the MIL-SPEC, may be acceptable for certain USCG applications. Given the substantial weight and space savings (even at 6 - 8 g/L ($50.0 - 66.6 \times 10^{-3}$ lbs/gal)), the development of this technology is still worthwhile.

14 RECOMMENDATIONS

Although the current commercially available solid AFFF stick technology is not viable for use on USCG ships, further development of the technology may be worthwhile in terms of long-term shipboard space and weight reductions (or alternatively, increased protection by deployment of more AFFF handlines). The USCG should encourage the development of solid AFFF and evaluate any new formulations/equipment. The goal should be an agent having fire performance equal, or close to, that provided by MIL-SPEC AFFF.



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APPENDIX A MATERIAL SAFETY DATA SHEET FOR SOLID AFFF STICK

MATERIAL SAFETY DATA SHEET IDENTITY - "SOLID FOAM" FIRE FIGHTING STIK

SECTION I. Chemical Product and Company Identification

Product Name: "Solid Foam" Fire Fighting Stik
Product Usage: Cylindrical solid foaming agent for use in certain cartridge type fire extinguishing foam nozzles
Distributor: Buckeye Fire Equipment Company
110 Kings Road
Kings Mountain, NC 28086
Telephone: 704.739.7415
Emergency: BUCKEYE 1.817.633.3626 or 1.877.391.3626
CHEMTREC 1.800.424.9300

Revision Date: 04/16/07

SECTION II. Hazard Identification and Emergency Overview

Emergency Overview: None of the chemicals in this product are under SARA reporting requirements or have SARA Threshold Planning Quantities or CERCLA Reportable Quantities. This product is not defined as hazardous under U.S. Department of Transportation 49 CFR 172 or by Transport Canada "Transportation of Dangerous Goods" regulations.

Appearance: Solid cylindrical shape, red color, slight ammonia/mild disinfectant odor.

Adverse Health Effects and Symptoms: No adverse health effects expected if the product is handled in accordance with this Safety Data Sheet. Symptoms that may arise if the product is mishandled are irritation to the skin and eyes, gastrointestinal disturbances if ingested. Avoid inhalation of mist or vapors.

Hazard Symbols:

HMIS RATINGS:

Health 2
Flammability 0
Reactivity 0

Personal Protective Equipment: use eye protection, gloves, and appropriate skin protection (See Section 8)

WHMIS (Canadian Workplace Hazardous Materials Identification)

D2B- May irritate eyes, mucous membranes, or skin

SECTION III. Composition/Information on Ingredients

Proprietary polymer
Nonionic active surfactants
Proprietary mixture of fluorosurfactants and hydrocarbon surfactants

SECTION IV. First Aid Measures

Eye Exposure- Flush eyes at eye wash station for 15 minutes and repeat until pain-free. If irritation develops or persists or vision changes occur, seek medical attention.

Skin Exposure- Wash with plenty of soap and water. If irritation develops or persists, seek medical attention.

Inhalation- If irritation develops after vapor/mist has been inhaled, move victim to fresh air. Trained personnel may administer oxygen if breathing is difficult. If irritation persists, seek medical attention.



MATERIAL SAFETY DATA SHEET IDENTITY- "SOLID FOAM" FIRE FIGHTING STIK

Ingestion: If victim is conscious and alert, give 2-3 glasses of water to drink. Do not leave victim unattended. Never induce vomiting or give anything by mouth if the victim is unconscious. Seek immediate medical attention.

Medical Conditions Possibly Aggravated by Exposure: Skin contact may aggravate existing chronic skin conditions.

SECTION V. Firefighting Measures

Extinguishing Media: N/A. This product is an extinguishing agent. It is nonflammable and noncombustible.

Special Firefighting Procedures: N/A

Unusual Fire and Explosion Hazards: This product may decompose in fire and release oxides of sulfur and nitrogen as well as carbon monoxide gas (Refer to Section X).

Sensitivity to Mechanical Impact or Static Discharge: None

SECTION VI. Accidental Release Measures

Personal Precautions: Avoid contact with skin and eyes.

Environmental Precautions: Avoid release of large quantities of product into sewer or waterways.

Cleanup: Sweep/shovel up material. Place in a suitable container for disposal. Traces of the material may be flushed away with water.

SECTION VII. Handling and Storage

Safe Handling: Avoid eye, respiratory, and skin exposure. Use the appropriate personal protective equipment when handling. Wash thoroughly after handling (Refer to Section VIII).

Safe Storage: Product should be stored sealed in its original container in a cool, dry area. Avoid excessive heat. Use in well-ventilated areas.

SECTION VIII. Exposure Controls and Personal Protection

Respiratory Protection: During the use of this product on fires, exhaust gases and products of incomplete combustion are the main respiratory hazards. The need for respiratory protection is not likely for short-term use in well-ventilated areas. Long term exposures may require the use of positive pressure supplied air respirators or self-contained breathing apparatus.

Eye Protection: Wear safety glasses, chemical goggles, or splash shield.

Skin Protection: Use nitrile, latex, or similar gloves to minimize skin contact. Good personal hygiene practices are essential. After handling the product, avoid food, tobacco products, or other means of transferring the product from hand to mouth until after thoroughly washing.

SECTION IX. Physical and Chemical Properties

Appearance and Odor: Solid cylindrical shape, red color, slight ammonia/mild disinfectant odor.

pH: 8.0 – 9.0 (5% Aqueous Solution)

Melting Point: > 110° F. (Point where product shape may distort)

Specific Gravity: 1.066

Flash Point: N/A

Flammability: N/A

Solubility: 100%

SECTION X. Stability and Reactivity

Stability: Stable

Incompatibles: Strong oxidizers and strong alkalies

Decomposition Products: Oxides of sulfur and nitrogen may be formed.

Conditions to Avoid: Temperatures above 100° F. Product shape may distort.



MATERIAL SAFETY DATA SHEET IDENTITY- "SOLID FOAM" FIRE FIGHTING STIK

SECTION XI. Toxicological Information

Routes of Entry:

Eye Contact:	May cause mild transient irritation
Skin Contact:	May cause mild transient irritation and/or dermatitis
Inhalation:	Inhalation is not anticipated to be a problem
Ingestion:	May cause gastrointestinal disturbances

Chronic Toxicity: No data available.

SECTION XII. Considerations for Disposal

This product is not a RCRA characteristically hazardous or listed hazardous waste. Dispose of according to state or local laws, which may be more restrictive than federal regulations. Be aware that product used on a fire may be altered or contaminated and thereby require different disposal considerations.

SECTION XIII. Transportation Information

This product is not defined as a hazardous material under U.S. Department of Transportation 49 CFR 172, or by Transport Canada "Transportation of Dangerous Goods" regulations.

SECTION XIV. Regulatory Information

TSCA, US: Listed

OSHA Hazard Category: Skin or eye irritant

SARA Hazard Categories 311/312: Acute, Not Hazardous

SECTION XV. Other Information

Some of the information presented and conclusions drawn herein are from sources other than direct test data on the product itself. The information in this MSDS was obtained from sources deemed reliable, however, the information is provided without any warranty, express or implied, regarding its correctness. The conditions or methods of handling, storage, use, and disposal of the product are beyond Buckeye's control. Buckeye does not assume responsibility and expressly disclaims liability for loss, damage or expense arising out of or in any way connected with the handling, storage, use, or disposal of the product.



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APPENDIX B DATA SHEET AND PROCEDURAL CHECK LIST

afspctst. wpd

NRL AFFF SPECIFICATION FIRE TEST FORM MIL-F-24385F

TEST# _____ DATE: _____ Time: _____
AGENT TYPE: _____ Type 3/ Type 6
Lot #: _____
WATER: Fresh _____ / Salt _____ STRENGTH: Full/ Half/ Quintuple FLOW RATE: _____ gpm
AFFF Concentration In Mixture: _____
TEMPERATURE: Air _____ °C / F; Water _____ °C / F; Fuel: _____ °C / F; Solution _____ °C / F
FUEL TYPE: _____

EXTINGUISHMENT

28 ft2 FIRE TEST

Times in min:sec

_____ fuel poured (30 sec) (10 gal)

_____ 0:00 ignition (_____ second preburn)

_____ End of preburn commence extinguishment (Apply
foam for full 90 sec)
(Move BBP in & light prior to fire out)

_____ **NOTE TIME FIRE OUT**

_____ End of preburn + 1:30 secure foam application

BURNBACK

_____ **NOTE TIME** insert 1 ft. fire pan (1
gal fuel) (Remove pan when burn back fire
Self sustaining)

_____ Time pan removed

_____ **NOTE TIME** 25 % (7 ft2) of pan area
is Involved in flames.

BB pan In:

5%:

10%:

15%:

20%:

25%:

BB Pan Out

_____ Testing foam and drainage

WEIGHT: #1: _____ #2: _____

EXPANSION RATIO: #1: _____ #2: _____

DRAINAGE TIME: # 1: _____ #2: _____



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